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ABSTRACT

Previous research concerning the cognitive abilities of high school students has indicated that a substantial number of students enrolled in secondary science courses do not conceptualize at the formal-operational level. Further, results indicate that achievement levels in chemistry coursework are significantly affected by, not only cognitive abilities, but also instructional methods and specific classroom strategies. This annotated bibliography consolidates research results involving achievement of high school students in chemistry courses and contains the following: (1) an introduction with definitions of educational-psychological terms and relevant scientific vocabulary; (2) three lists of journal annotations involving research results about achievement in secondary school chemistry courses indexed under the three categories: cognitive ability, instructional methods, and classroom strategies; (3) extensive summaries, in the style of a review of the literature, that compare and contrast the citations in each category, with accompanying conclusions; (4) explicit recommendations prompted by the research, not only for the improvement of student achievement, but also for the enhancement of the teaching/learning process in high school chemistry courses; and (5) an alphabetical list of the citations. (JJK)

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AN ANNOTATED BIBLIOGRAPHY OF THE LITERATURE CONCERNING THE FACTORS AFFECTING STUDENTS' ACHIEVEMENT IN HIGH SCHOOL CHEMISTRY COURSES

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INTRODUCTION

An area of study for many researchers in science has been the cognitive abilities of students enrolled in science courses. It has been determined through research that a substantial number of students enrolled in high school science courses did not think on the formal-operational level (Chiapetta, 1976). Since many chemistry concepts have been classified as abstract, some researchers focussed on high school chemistry courses and on the cognitive abilities of students within those courses. Results of the research indicated that cognitive ability was a major influence on student achievement within the chemistry courses (Cantu and Herron, 1978; McNaught, 1982; Chandler, Treagust, and Tobin, 1987; Staver and Jacks, 1988).

Since cognitive ability was shown to have a significant role in determining student achievement in high school chemistry courses, other researchers centered their studies on the effects that instructional methods had on achievement within those courses. Analysis of that research indicated that such instructional methods as mastery learning techniques (Swanson, 1977; Dillashaw and Oakey, 1983) and small group laboratory techniques (Harty and Al-Faleh, 1983) enhanced student achievement.

Finally, researchers analyzed specific teaching strategies that were used to teach particular chemical concepts. The results of those studies indicated that problem solving strategies (Gabel and Sherwood, 1983; Gabel and Sherwood, 1984), the use of concrete materials (Goodstein, 1978; Gabel and Sherwood, January 1980; Howe and Durr, 1982), and

testing techniques (Lazonby, Morris, and Waddington, 1985; Cassels and Johnstone, 1984) were among a variety of techniques that were determined to have improved student achievement in high school chemistry courses.

STATEMENT OF THE PROBLEM AND PURPOSE OF THE STUDY

Research has shown that students' achievement in high school chemistry courses was dependent upon, and was influenced by many factors. This study was conducted to identify the factors that affected students' achievement in high school chemistry courses. Some of the factors that were identified could be utilized by chemistry teachers to enhance learning and achievement in their classrooms.

ORGANIZATION OF THE STUDY

This study was organized into three major categories that were identified in research as factors affecting students' achievement in high school chemistry courses: (1) cognitive abilities affecting achievement, (2) instructional methods affecting achievement, and (3) teaching strategies affecting achievement.

The annotations in each category were arranged in alphabetical order.

LIMITATIONS OF THE STUDY

The purpose of this study was to review the literature concerned with the factors affecting students' achievement in high school chemistry courses. Research that focussed on achievement in college chemistry

courses was not included in this study.

There were many research articles concerned with the factors affecting students' achievement in high school chemistry courses. However, a time limitation prevented investigation into all the related materials.

DEFINITION OF TERMS

abstract concept -- ". . . those that do not have perceptible instances or have relevant or defining attributes that are not perceptible." (Cantu, 1978: 135)

application preference -- ". . . preference for identifying a practical application related to information provided." (McNaught, 1982: 177)

Bloom's Learning for Mastery (LFM) -- a mastery learning approach that ". . . compares the success and positive reinforcement necessary for survival in our society by describing procedures which offer all students the opportunity to achieve at the same level as the top 25% of students in traditional classrooms." (Swanson, 1977: 2)

chemical change -- ". . . change not only in physical appearance, but also in basic identity; that is one substance converted into another." (Brown and LeMay, 1988: 5)

cognitive preferences -- ". . . different modes of attending to the subject matter of a course." (McNaught, 1982: 177)

concrete concepts -- ". . . ones that have defining attributes and examples that are observable. . ." (Cantu, 1978: 135)

concrete-operational -- "stage of development, concrete operations . . . according to Piaget, the period in the child's mental development from preschool through upper elementary grades (about junior high school) in which analysis of situations and events is based largely upon present perceivable elements." (Good, 1973: 553)

corteria -- ". . . quick in reacting, fast in ideomotor performance and high in general cortial energy." (Sakmyser, 1974: 74)

disembedding ability -- ". . . the ability to identify simpler figures embedded in complex ones . . . the extent of students' field independence." (Staver and Jacks, 1988: 765)

discovery instructional approach -- ". . . means for teaching not only scientific concepts and principles, but also for developing science attitudes on the part of learners." (Mulopo and Fowler, 1987: 219)

electrolyte -- ". . . solutes existing in aqueous solution as ions." (Brown and LeMay, 1988: 430)

equilibrium -- ". . . when the rate of the forward reaction equals the rate of the reverse reaction." (Brown and LeMay, 1988: 430)

expansion phase -- learning cycle phase -- "gives students the opportunity to expand the meaning, usefulness, and general understanding of the newly invented concept." (Abraham and Renner, 1986: 122)

exvia -- ". . . tendency toward social interaction." (Sakmyser, 1974: 72)

Flanders' Scale -- ". . .a 10-category system . . . measuring teacher-student interaction. . ." (Wolfson, 1973: 285)

formula approach -- problem solving method where ". . . the student employed or used a formula to solve the problem." (Anamuah-Mensah, 1986: 762)

formal operational -- "stage of development, formal operations . . . according to Piaget, the final stage in mental development of the child in which he is able to use symbols and deal with abstractions." (Good, 1973: 553)

gathering data phase -- learning cycle phase ". . . an activity which gives students experience with the concepts to be developed before the concepts are discussed, read about, or named." (Abraham and Renner, 1986: 121)

I/D ratio -- " . . . a measure of the number of times a teacher encourages a student to the number of times the teacher discourages the student . . . " (Wolfson, 1973: 283)

illusionary errors -- type of error ". . . which arise when observations are reported which, in reality are absent from the system under examination." (Kempa and Ward, 1975: 70)

INRC group -- cognitive transformations based on a ". . . Piagetian logical structure or model . . . contains four elements . . . identity (I), negation (N), reprocity (R), and correlativity (C) . . . used to distinguish the concrete-operational child from the formal-operational adolescent." (Wheeler and Kass, 1978: 223)

invention phase -- learning cycle phase ". . . activity where the teacher and/or student literally invents the concept from the data." (Abraham and Renner, 1986: 122)

invia -- ". . . general inhibition in all aspects of social interaction." (Sakmyser, 1974: 72)

Keller's Personalized System of Instruction (PSI) -- " . . . an alternate form of mastery learning . . . prescribes procedures and methods to attain the same high achievement level and to develop an increased positive attitude toward instruction and learning in schools." (Swanson, 1977: 2)

kinetics -- " . . . the area of chemistry concered with the speeds, or rates, at which chemical reactions occur." (Brown and LeMay, 1988: 483)

Le Chatelier's Principle -- " . . . If a system at equilibrium is disturbed by a change in the temperature, pressure or the concentration of one of the components, the system will tend to shift its equilibrium position as to counteract the effect of the disturbance." (Brown and LeMay, 1988: 483)

lecture demonstration -- " . . . teaching strategy consisting of frequent diagnosis and remediation of learning difficulties prior to summative testing." (Dillashaw and Oakey, 1983: 203)

mastery learning -- " . . . teaching strategy consisting of frequent diagnosis and remediation of learning difficulties prior to summative testing." (Dillashaw and Oakey, 1983: 203)

memory preference ". . . preference for remembering a specific fact or term related to information provided." (McNaught, 1982: 177)

mole -- " . . . number of atoms, molecules, or formula units" . . . 6.022×10^{23} particles . . ." (Brown and LeMay, 1988: 75)

qualitative analysis -- " . . process whereby mixtures of ions are separated and identified . . ." (Zumdahl, 1986: 116)

omission error -- ". . . occurs when the subject fails to perceive changes which are clearly observable." (Kempa and Ward, 1975: 70)

pathemia -- " . . . depressed, frustrated, and neurotic." (Sakmyser, 1974: 74)

physical change -- " . . .process in which a material changes it's physical appearance, but not it's basic identity." (Brown and LeMay, 1988: 4)

periodic table -- " . . . arrangement of elements in order of increasing atomic number, with elements having similar properties placed in vertical columns." (Brown and LeMay, 1988: 41)

Piagetian-based instruction -- ". . . consists of: (1) large group instruction, (2) small group activities or laboratory exercise and audio-visual instruction, and (3) self-paced and self-driven individual study." Kletzly, 1980: 25)

principle preference -- " . . . preference for identifying the fundamental principles underlying the information provided or drawing conclusions based on underlying principles." (McNaught, 1982: 17)

proportional approach -- ". . . involves the use of a ratio or proportional relations." (Anamuah Mensah, 1986: 762)

pseudo-examples -- ". . . perceptible entities that are used to focus attention on critical and variable attributes of an abstract concept." (Cantu, 1978: 436)

questioning preference -- " . . . preference for critical questioning or challenging of information provided or recognition of a limitation or extension of the information." (McNaught, 1982: 177)

reaction rate -- " . . . speed, or rate, at which a chemical reaction occurs." (Brown and LeMay, 1988: 483)

reasoning pattern -- " . . . an identifiable and reproducible thought process directed at a type of task." (Krajcik and Haney, 1987: 25)

small group lab instruction -- " . . . type of instruction which may facilitate the development of process skills and the spirit of inquiry and orient students to a realistic role of scientists." (Harty and Al-Faleh, 1983: 862)

thermochemistry -- " . . . relationship between chemical reactions and energy changes." (Brown and LeMay, 1988: 101)

traditional instruction -- " . . . mode of instruction consisting of (1) lecturing from the textbook, (2) reviewing notes, (3) reading the textbook pages as assigned, (4) working the questions at the end of the chapter . . . " (Kletzly, 1980: 24)

volumetric analysis -- " . . . a technique in which one solution is used to analyze another." (Zumdahl, 1986: 126)

ANNOTATIONS

ACHIEVEMENT AS AFFECTED BY COGNITIVE ABILITY

Anamuah-Mensah, J. "Cognitive Strategies Used by Chemistry Students to Solve Volumetric Analysis Problems." Journal of Research in Science Teaching 23 (9): 759-769, December 1986.

Forty-seven grade 12 chemistry students from Canada were the subjects of a study with two purposes: (1) to determine the cognitive strategies utilized by students in solving volumetric analysis problems, and (2) to identify the difficulties arising during the problem solving sequence. Students were preliminarily assigned to achievement groups based on their performance on a Volumetric Analysis Test developed by the author. The students were asked to determine the concentration of an acid using a known concentration of a base. Students verbally discussed their problem solving method with the investigator. Upon analysis of the data, Anamuah-Mensah made seven conclusions: (1) The Formula Approach and Proportional Approach were the two methods used by the students to solve the volumetric analysis problems; (2) The Formula Approach was utilized by the majority of the students; (3) Students using the Formula Approach did not understand the relationships among the variables in the problems; (4) Students using the Proportional Approach showed an understanding of the relationships among the variables in the problems; (5) There was no significant relationship between the type of strategy used and achievement; (6) Students classified as high achievers were more successful in problem solving than were the students classified as low achievers; (7) Difficulties in problem solving arose when students did not comprehend the proportional relationship between volume and concentration.

Anamuah-Mensah, Jophus, Gaalen Erickson, and Jim Gaskell. "Development of a Path Analytical Model of Students' Performance in Chemistry." Journal of Research in Science Teaching 24 (8): 723-738, November 1987.

Two-hundred sixty-five grade 12 chemistry students from Canada were the subjects of a study designed to determine the method of problem solving utilized by students who were successful at solving volumetric analysis problems. The students were classified according to their ability to comprehend the algorithms used to solve the problems. The students were further classified according to proportional reasoning ability after assessment by the Classroom Test of Formal Operations. Performance on volumetric analysis problems was assessed by means of the Volumetric Analysis Test (VAT). Analysis of the data led the authors to conclude that proportional reasoning ability did not affect the performance of students using algorithms without comprehension, but did affect the success of the students using algorithms with comprehension.

Cantu, Luis L. and J. Dudley Herron. "Concrete and Formal Piagetian Stages and Science Concept Attainment." Journal of Research in Science Teaching 15 (2): 135-143, January 1978.

One-hundred thirty-seven high school chemistry students were the subjects of a study designed to determine the effect that the use of pseudo-examples had on the students' understanding of abstract science concepts. A comparison was made between concrete-operational thinkers and formal-operational thinkers. Cognitive level was measured by means of a Longeot Test. Six chemical concepts, three concrete and three abstract, were studied. Achievement and retention tests were used to assess performance. Upon analysis of the data, the authors concluded that formal-operational thinkers achieve at significantly higher levels than concrete-operational thinkers in both concrete and abstract concepts. Additionally, the authors found that both formal-operational thinkers and concrete-operational thinkers benefitted from the use of pseudo-examples.

Chandran, Sarath, David F. Treagust, and Kenneth Tobin. "The Role of Cognitive Factors in Chemistry Achievement." Journal of Research in Science Teaching 24 (2): 145-160, February 1987.

Three-hundred fifty-nine grade 11 Australian chemistry students were the subjects of a study designed to determine the role and influence four cognitive factors had on chemistry achievement. The four factors were formal reasoning ability, prior knowledge, memory capacity, and field dependence/independence. The factors were measure by The Test of Logical Thinking (TOLT), Science Item Test Bank, Hidden Figures Test, and Figural Intersection Test respectively. Chemistry achievement was determined by three tests designed to measure lab applications, chemical calculations, and content knowledge. Upon analysis of the data, the authors concluded that formal reasoning ability and prior knowledge were significantly correlated with achievement in lab applications, chemical calculations, and content knowledge. The authors further determined that memory capacity and field dependence/independence were not significantly correlated with chemistry achievement. The authors recommended further research with memory capacity and field dependence/independence.

Krajcik, Joseph S. and Richard E. Haney. "Proportional Reasoning and Achievement in High School Chemistry." School Science and Mathematics 87 (1): 25-32, January 1987.

One-hundred seventy 11th and 12th grade male college preparatory school students were the subjects of a study designed to determine the reasoning patterms necessary for success in high school chemistry. Students' cognitive abilities were assessed by means of a Lawson Test. The American Chemical Society Exam was used to measure chemistry achievement. Analysis of the data indicated that achievement of students classified as formal-operational was significantly higher than that of students classified as concrete-operational. For exam items that were identified as discriminators, the results indicated that solutions to those items required the use of proportional reasoning. The authors concluded that proportional reasoning ability was necessary for achievement in high school chemistry courses.

McNaught, Carmel. "Relationship Between Cognitive Preferences and Achievement in Chemistry." Journal of Research in Science Teaching 19 (2): 177-186, February 1982.

Three hundred four grade 12 Australian chemistry students were the subjects of a study designed to determine whether cognitive preferences were related to achievement in chemistry and in what ways the preferences were related to achievement. Four cognitive preferences were identified and studied: (1) memory, (2) application, (3) questioning, and (4) principles. Cognitive preferences were assessed through means of a cognitive preference test. Chemistry achievement was measured through the High School Chemistry Exam. Upon analysis of the data, McNaught concluded that all cognitive preferences studied were significantly correlated with achievement in chemistry and that the preferences were related to achievement in specific types of tasks in the achievement exam.

Staver, John R. and Tom Jacks. "The Influence of Cognitive Reasoning Level, Cognitive Restructuring Ability, Disembedding Ability, Working Memory Capacity, and Prior Knowledge on Students' Performance on Balancing Equations by Inspection." Journal of Research in Science Teaching 25 (9): 763-775, December 1988.

Eighty-three high school chemistry students were the subjects of a study designed to determine the factors that influence the students' abilities to balance chemical equations. Five factors, cognitive reasoning level, cognitive restructuring ability, disembedding ability, working memory capacity, and prior knowledge were studied. The factors were measured by The Test of Logical Thinking (TOLT), Purdue Visualization of Rotations Test, Find-A-Shape Puzzle, Reading Span Test, and author made tests repectively. Performance was assessed by a posttest. After analysis of the data, Staver and Jacks concluded that when considered independently, prior knowledge was significantly correlated with students' understanding of balancing equations. When prior knowledge, restructuring ability, and working memory capacity were considered together, only restructuring ability was found to significantly influence students' performance. Additionally, the authors determined that working memory capacity, prior knowledge, and restructuring ability were highly correlated with students' achievement on specific posttest items. The authors further noted that working memory capacity did not influence overall achievement.

Wheeler, Alan E. and Heidi Kass. "Proportional Reasoning in Introductory High School Chemistry." Educational Resources Information Center, ED 139 620, National Association for Research in Science Teaching, March 1977, 31 pages.

Three-hundred nine grade 10 chemistry students from Canada were the subjects of a study designed to determine whether proportional reasoning was a major factor in the achievement of chemical concepts. The chemical concepts studied were nomenclature, formula writing, and stoichiometry. A Neo-Piagetian Reasoning Test served as a measure of students' cognitive abilities. A General Proportionality Test was used to assess students' levels of proportional reasoning ability. Four Chemistry Proportionality Tests were used to measure chemistry achievement. After analysis of the data, Wheeler and Kass made three conclusions: (1) Proportional reasoning ability was significantly correlated with achievement in chemistry; (2) Proportional reasoning ability was related to cognitive level; (3) Chemistry instruction in proportional reasoning did not increase proportional reasoning ability in non-chemistry contexts.

Wheeler, Alan E. and Heidi Kass. "Student Misconceptions in Chemical Equilibrium." Science Education 62 (2): 223-232, February 1978.

Ninety-nine 12th grade Canadian chemistry students were the subjests of a study with three purposes: (1) to determine the types of misconceptions related to the chemical concept of equilibrium, (2) to determine how the misconceptions were related to achievement, and (3) to ascertain how the misconceptions were related to cognitive ability. Students' misconceptions were identified by use of the Misconception Identification Test (MIT) that was developed by the authors. The Chemistry Achievement Test (CHAT) based upon the textbook used in this study was used to measure chemistry achievement. Cognitive ability was assessed by the Piagetian model of cognitive structures, the INRC group. Analysis of the data indicated that the misconceptions of the equilibrium constant, Le Chatlier's Principle, and competing equilibria were associated with achievement. Misconceptions of competing equilibria, mass and concentration, and reaction rate and extent were associated with cognitive ability.

ACHIEVEMENT AS AFFECTED BY INSTRUCTIONAL METHODS

Abraham, Michael R. and John W. Renner. "The Sequence of Learning Cycle Activities in High School Chemistry." Journal of Research in Science Teaching 23 (2): 121-143, February 1986.

Students of six high school chemistry classes were the subjects of a study designed to determine the effects that altering the sequence of phases of a learning cycle had on the students' learning of chemical concepts and their attitudes about science. The three phases of the learning cycle were gathering data (G), invention (I), and expansion (E). Physical and chemical changes and thermochemistry were the chemical concepts taught in separate experiments. After analysis of the data, Abraham and Renner concluded that optimal learning and achievement were dependent upon the position of the invention phase. Additionally, the authors concluded that the position of the invention phase was dependent upon the type of chemical concept being taught. For review concepts, the ideal location of the invention phase was between the other two phases. For new concepts, the ideal location of the invention phase was dependent upon the cognitive abilities of the students. Concrete-operational students achieved at higher levels when the invention phase was placed last. Formal-operational students achieved at higher levels when the invention phase was placed first. Students exhibited more positive science attitudes when the invention phase was placed last.

Dillashaw, F. Gerald and James R. Oakey. "Effects of a Modified Mastery Learning Strategy on Achievement, Attitudes, and On-Task Behavior of High School Chemistry Students." Journal of Research in Science Teaching 20 (3): 203-211, March 1983.

One-hundred fifty-six first year chemistry students were the subjects of a study designed to determine the effects that a modified mastery learning technique had on the achievement, science attitudes, and on-task behavior of the students. Additionally, the authors sought to determine whether the modified methods would alter the on-task behavior of the students. The students were randomly assigned to three groups: (1) traditional instruction group, (2) mastery learning with student directed remediation group, and (3) mastery learning with teacher directed remediation group. Upon analysis of the data, the authors determined that both modified groups demonstrated higher achievement than the traditional instruction group. Higher positive attitudes were found to be correlated with the student managed remediation group. Both modified groups showed an increase in on-task behavior.

Hardy, Clifford A. "CHEM Study and Traditional Chemistry: An Experimental Analysis." Science Education 54 (3): 273-276, March 1970.

Two-hundred high school chemistry students were the subjects of a study designed to compare the achievement levels and critical thinking abilities in a CHEM Study course to those in a traditional chemistry course. Additionally, the author sought to determine whether achievement was dependent upon cognitive ability and upon the type of instruction used. Finally, the author analyzed the relationship between student achievement and critical thinking level to other measured variables. Critical thinking ability was measured by the Watson-Glaser Critical Thinking Appraisal. Chemistry achievement was measured by the American Chemical Society-National Science Teachers Cooperative Examination Form 1967. After analysis of the data, Hardy concluded that students in the CHEM Study course achieved at significantly higher levels than the students in the traditional chemistry course. In addition, the author found that critical thinking levels of students were not significantly different in either of the groups. Analysis of the interaction between type of instruction and cognitive ability with achievement and critical thinking ability did not reveal any significant relationships. Hardy noted that the factor most influencing chemistry achievement and critical thinking ability was the student's I.Q.

Harty, Harold and Nasser Al-Faleh. "Saudi Arabian Students' Chemistry Achievement and Science Attitudes Stemming from Lecture Demonstration and Sma!! Group Teaching Methods." Journal of Research in Science Teaching 20 (9): 861-866, December 1983.

Seventy-four 11th grade Saudi Arabian chemistry students were the subjects of a study designed to determine the effects that a lecture demonstration method and a small group lab instruction method had upon the students' achievement in chemistry and upon their attitudes towards science. Chemical concepts taught included the topics of colloids, solubility, percent composition, and solution concentrations. Chemistry achievement tests that were correlated with the concepts taught were used to measure the student performance. Student attitudes were assessed by the use of An Attitude Survey for Junior High Science. Upon analysis of the data, the authors concluded that students of the small group lab instruction achieved at significantly higher levels than the students of the lecture demonstration instruction. Further analysis revealed that students of the small lab group exhibited more positive attitudes towards science.

Kletzly, Nellie E. "The Effects of Two Methods of Teaching Abstract Topics in High School Chemistry." Educational Resources Information Center, ED 199 063, Sam Houston State University, August 1980, 86 pages.

Seventy-eight high school chemistry students were the subjects of a study designed to determine the effects of traditional and Piagetian-based instruction on chemistry achievement. Students were classified by cognitive level which was measured by a validated author developed Piagetian test. Students were randomly assigned to the traditional and Piagetian-based instruction groups. The chemical concepts taught were the mole and atomic theory. Chemistry achievement was measured by a criterion test. Upon analysis of the data, Kletzly concluded that Piagetian-based instruction resulted in higher chemistry achievement for both concrete-operational students and formal-operational students. The author also concluded that Piagetian-based instruction resulted in significantly higher achievement for students classified as transitional-operational.

Mulopo, Moses M. and Seymour H. Fowler. "Effects of Traditional and Discovery Instructional Approaches on Learning Outcomes for Learners of Different Intellectual Development: A Study of Chemistry Students in Zambia." Journal of Research in Science Teaching 24 (3): 217-227, March 1987.

One-hundred twenty 11th grade male chemistry students from Zambia were the subjects of a study designed to determine the differential effects of traditional and discovery methods of instruction on the teaching of chemical topics. Additionally, the authors sought to determine the differential effects upon the understanding of science and scientists and upon the attitudes of the students towards science. The cognitive abilities of the students were assessed by the CAP Cognitive Incidents Exam. Upon analysis of the data, Mulopo and Fowler concluded that the traditional approach of instruction resulted in significantly higher achievement of the chemical topics studied and that the discovery method of instruction was more effective at developing understanding about science and scientists and for promoting more positive attitudes about science. The authors further concluded that there was no significant correlation between students' cognitive abilities and method of instruction and that formal-operational students achieved at significantly higher levels than did concrete-operational students.

Sakmyser, Diane D. "Comparison of Inductive and Deductive Programmed Instruction on Chemical Equilibrium for High School Chemistry Students." Journal of Research in Science Teaching 11 (1): 67-77, January 1974.

One-hundred fifty high school chemistry students were the subjects of a study that compared inductive and deductive programmed instruction methods on the chemical concept of equilibrium. Students' reading abilities, algebra abilities, cognitive styles, and personality traits were assessed by the Nelson Denny Reading Test (NDRT), the Lankton First Year Algebra Test (LFYAT), the Siegel's Educational Set Scale (ESS), and the Cattell's High School Personality Questionnaire (HSPQ) respectively. Chemistry achievement was measured by two criterion tests. The students were randomly assigned to each instruction group. Upon analysis of the data, the author concluded that there was no significant difference in the achievement of students in either programmed instruction course. Additional analysis of the data led the author to conclude that students with high reading abilities who were in the deductive program, showed significantly higher achievement than students with low reading abilities in the same program. Students with strong algebra abillties who were in the inductive program, achieved at significantly higher levels than students with weak algebra abilities in the same program. Cognitive style did not affect achievement in either program. Personality traits such as exvia and invia, anxiety, cortertia and pathemia, field independence, and creativity did affect the achievement of students in each of the programmed courses.

Swanson, David H. "A Comparison of Mastery Learning Feedback Systems Affecting Achievement in Chemistry." Educational Resources Information Center, ED 139 650, American Educational Research Association, April 1977, 17 pages.

Fifty-three high school chemistry students were the subjects of a study designed to determine the effects that two mastery learning remediation systems had on achievement in chemistry. The two systems were the Keller Personalized System of Instruction (PSI) and Bloom's Learning for Mastery (LFM). The students were randomly assigned to one of three treatment groups: (1) traditional instruction group, (2) Keller's PSI instruction group, and (3) Bloom's LFM instruction group. The chemical topics studied were equilibrium and kinetics. Chemistry achievement was measured by a posttest and a retention test. Analysis of the data led Swanson to conclude that both mastery feedback systems resulted in significantly higher achievement than did the traditional system. The author also concluded that Bloom's LFM system resulted in greater achievement than did Keller's PSI program over the traditional system. Both mastery systems resulted in achievement of greater number of objectives than did the traditional system.

Wolfson, Morton L. "A Consideration of Direct and Indirect Teaching Styles with Respect to Achievement and Retention of Learning in Science Classes." Journal of Research in Science Teaching 10 (4): 285-290, April 1973.

One-hundred sixty high school chemistry students and one-hundred sixty junior high school general science students were the subjects of a study designed to determine the effect that teacher-student interactions (I/D ratio) had on achievement and retention of science topics. Teacher-student interactions were measured by means of the Flanders' Interaction Analysis Scale. Science achievement was measured by use of standardized achievement exams. Upon analysis of the data, Wolfson concluded that students of high I/D ratio teachers, both in chemistry and general science, showed a significantly higher achievement and retention of science concepts than did students of low I/D ratio teachers. Wolfson recommended further research in the area of retention tests.

ACHIEVEMENT AS AFFECTED BY SPECIFIC TEACHING STRATEGIES

Cassels, J. R. T. and A. H. Johnstone. "The Effect of Language on Student Performance on Multiple Choice Tests in Chemistry." Journal of Chemical Education 61 (7): 613-615, July 1984.

Over 3600 high school chemistry students were the subjects of a study designed to determine the effect that language had on achievement in multiple choice chemistry tests. Five language patterns were assessed: (1) key word changes, (2) terms of quantity changes, (3) negative to positive changes, (4) complex clause changes, and (5) passive to active tense changes. Changes in key words involved the alteration of complex scientific terms to simple terms. Quantity changes involved the exchange of the terms "least" to "most." Negative to positive changes resulted from the substitution of "is" for "is not." Complex clauses were shortened by removal of unnecessary data. Verb tense changes switched "does" to "is." Analysis of the data led the authors to conclude that all language pattern changes, except verbal tense changes, resulted in higher achievement on multiple choice chemistry tests.

DeBoer, George E. "The Effect of Retesting on End-of-Semester Performance in High School Chemistry at Three Levels of Previous Science Achievement." Journal of Research in Science Teaching 18 (3): 261-267, May 1981.

Ninety-five high school chemistry students were the subjects of a study with three purposes: (1) to determine how the end-of-semester retesting of course objectives affected students of different achievement levels, (2) to determine whether the opportunity of retesting caused students to delay studying for initial exams, and (3) to determine if the delay in studying was related to students' levels of prior achievement. Upon analysis of the data, the author concluded that end-of-semester retesting did improve course objectives achievement for low ability students. The author further concluded that procrastination did not affect the achievement of students at any level.

Gabel, Dorothy and Robert Sherwood. "The Effect of Student Manipulation of Molecular Models on Chemistry Achievement According to Piagetian Level." Journal of Research in Science Teaching 17 (1): 75-81, January 1980.

Three-hundred twenty-six high school chemistry students were the subjects of a study with two purposes: (1) to determine whether the long range use and manipulation of molecular models had an effect on achievement in chemistry, and (2) to determine whether the use of molecular models resulted in differential effects between concrete-operational students and formal-operational students. A modified Longeot Test was used to assess the cognitive levels of the students. Modified teacher exams and the American Chemical Society Test were used to assess chemistry achievement. Students were randomly assigned to treatment and control groups. Chemical topics studied included molecule formation, formula writing, balancing equations, molecular shapes, kinetics, equilibrium, and acid-base theory. From analysis of the data, Gabel and Sherwood concluded that chemistry students who manipulated molecular models throughout entire chemistry instruction, achieved at significantly higher levels than students who only observed the instructor handle the models. Additionally, the authors found that both concrete- and formal-operational students benefitted from the manipulation of the molecular models.

Gabel, Dorothy L. and Robert D. Sherwood. "Effect of Using Analogies on Chemistry Achievement According to Piagetian Level." Science Education 64 (5): 709-716, October 1980.

Two-hundred twenty-seven high school chemistry students were the subjects of a study with four purposes: (1) to determine the effects that the use of verbal analogies had on chemistry achievement, (2) to determine if the use of verbal analogies resulted in differential effects between concrete-operational students and formal-operational students, (3) to determine whether the use of verbal analogies had any effect on cognitive ability, and (4) to determine whether achievement was correlated with the understanding of the analogies. The cognitive levels of the students were measured by a modified Longeot Test. Achievement in chemistry was measured by modified teacher exams and the American Chemical Society Achievement Test, Form 1975, Part A. Students were randomly assigned to treatment and control groups. Upon analysis of the data, the authors made five conclusions: (1) The use of verbal analogies did not result in increased achievement for all students; (2) Additional practice problems assigned to the control groups benefitted students more than did the analogies used in the treatment groups; (3) The use of verbal analogies did not cause a change in cognitive level; (4) Students with lower formal reasoning ability were helped more by the use of analogies than were students with higher reasoning ability; (5) Students understanding the analogies achieved at significantly higher levels than did students not understanding the analogies.

Gabel, Dorothy L. and Robert D. Sherwood. "Facilitating Problem Solving in High School Chemistry." Journal of Research in Science Teaching 20 (2): 163-177, February 1983.

Six-hundred nine high school chemistry students were the subjects of a study with two purposes: (1) to determine whether specific problem solving strategies for four chemical topics were superior to others, and (2) to determine whether certain strategies were more beneficial to students exhibiting different verbal-visual preferences, proportional reasoning abilities, and math anxiety levels. The four instructional strategies were the factor-label method, the proportionality method, the analogy method, and the diagram method. The factor-label method and proportionality method were math oriented while the analogy and diagram methods were verbally and visually oriented. The chemical topics studied were the mole concept, the gas laws, stoichiometry, and molarity. Aptitude preferences were assessed through several types of aptitude tests. Chemistry achievement was measured by immediate and delayed tests, and the American Chemical Society-National Teachers Association Cooperative Examination in High School Chemistry Form 1975. Students were randomly assigned to one of four classrooms where only one problem solving strategy was taught. After treatment and upon analysis of the data, Gabel and Sherwood came to nine conclusions: (1) Students with high proportional reasoning abilities and low math anxiety levels achieved at significantly higher levels than students with low proportional reasoning abilities and high math anxiety levels; (2) The factor-label method was best for mole concept problems; (3) The proportionality method was best for the gas law problems; (4) For students exhibiting high verbal and low visual preferences, the best methods of problem solving were the analogy and diagram methods; (5) For students exhibiting low verbal and visual preferences, the factor-label method and the proportionality method were best; (6) The factor-label method was best and the diagram method was worst for students with low visual and math anxiety levels; (7) The diagram method was best and the factor-label method was worst for students with low visual preferences and high math anxiety levels; (8) The analogy method was best and the factor-label method was worst for students of high math anxiety levels and low proportional reasoning abilities; (9) The factor-label method was best and analogy method worst for students of low proportional reasoning abilities and math anxiety levels.

Gabel, Dorothy and Robert D. Sherwood. "Analyzing Difficulties with Mole-Concept Tasks by Using Familiar Analog Tasks." Journal of Research in Science Teaching 21 (8): 843-851, November 1984.

Three-hundred thirty-three high school chemistry students were the subjects of a study designed to determine whether students understood analogies used to solve mole concept problems in chemistry and to identify problems encountered in the problems themselves. Four exams were used to assess the students' capabilities in solving chemical problems concerned with moles, volume, and particles. After treatment and upon analysis of the data, the authors came to eight conclusions: (1) Particle size relationshlips in the problems did not affect students' abilities to solve the problems; (2) The use of scientific notation in chemical problems hindered students success in solving them; (3) Multiple step problems were more difficult to solve than were one step problems; (4) Problems involving multiplication were easier to solve than problems involving division; (5) Fractional quantities in problems hindered students' abilities to solve the problems; (6) The term "bag" was easier to understand than the term "billion"; (7) The indefinite article "a" and the term "one" presented difficulties in problem solving; (8) Students were successful in solving problems containing either large or small numbers that were not expressed in scientific notation.

Goodstein, Madeline. "The Use of Concrete Methods in Secondary Chemistry Instruction." Journal of Research in Science Teaching 15 (5): 361-366, June 1978.

Ninety-five high school chemistry students were the subjects of a study designed to determine the effects that the use of concrete models had on the understanding of chemical concepts. A comparison was made between students who were classified as concrete-operational thinkers and those classified as formal-operational thinkers. A modified Gray's Test was used to assess cognitive levels. Upon analysis of the data, the author concluded that achievement of formal-operational students was improved by the use of concrete materials. The use of concrete materials did not improve the achievement of students classified as concrete-operational. The author suggested that the use of concrete materials to enhance achievement was dependent upon the cognitive levels of the students, the conceptual difficulties of the concept being taught, and the method of instruction used to present that concept.

Howe, Ann C. and Beulah Durr. "Using Concrete Materials and Peer Interaction to Enhance Learning in Chemistry." Journal of Research in Science Teaching 19 (3): 225-232, March 1982.

Fifty-one high school chemistry students were the subjects of a study designed to determine the effect that the use of tangible materials combined with peer interaction had on learning in chemistry. The study compared concrete-operational thinkers and formal-operational thinkers. Cognitive levels were assessed by means of a Piagetian based test. Achievement and learning were assessed by two tests designed to measure comprehension and reasoning. The chemical topics taught were the mole concept and the Kinetic Molecular Theory of Gases. Students were randomly assigned to experimental and control groups. Upon analysis of the data, the authors concluded that for both groups, the achievement level of formal-operational thinkers was significantly higher than that of concrete-operational thinkers. Further analysis indicated that the achievement levels for concrete-operational thinkers in the experimental group were significantly higher than those of the concrete-operational thinkers in the control group. Achievement of formal-operational thinkers in the experimental groups was shown to be higher than that of formal-operational thinkers in the control group. The authors concluded that the use of concrete materials and peer facilitation increased learning for both concrete-operational and formal-operational thinkers.

Kempa, R. F. and J. E. Ward. "The Effect of Different Modes of Task Orientation on Observational Attainment in Practical Chemistry." Journal of Research in Science Teaching 12 (1): 69-76, January 1975.

One-hundred forty secondary level chemistry students were the subjects of a study designed to determine the effects that three methods of laboratory reports had on the students' abilities to make observations in laboratory chemistry. The methods utilized were open-ended reports, partial direction reports, and check list reports. Performance was assessed by a Chemistry Observation Test which measured ability of observing color change, solid and gas formation, and thermal changes in chemical reactions. Analysis of the data led the authors to conclude that the check list report resulted in the highest achievement and accounted for the highest illusionary error rate. The partial direction report resulted in lowest achievement and highest omission error rate. The author recommended further research with the check list report to ascertain if means were available to lower the illusionary error rate.

Lazonby, John N., Jane E. Morris, and David J. Waddington. "The Mole: Questioning Format Can Make a Difference." Journal of Chemical Education 62 (1): 60-61, January 1985.

Six-hundred fifty-two 16-year-old chemistry students from England, Wales, and Northern Ireland were the subjects of a study designed to determine the effect that questioning sequence had on the achievement of the chemical concept of the mole. Three exams with different question sequences were developed and utilized by the authors. Two exams were used to assess questioning sequence while one was used to assess inherent difficulties within individual steps of the problems. Upon analysis of the data, the authors ocncluded that achievement was significantly higher when the questioning format consisted of individual sequential steps. Lowest achievement occurred when the questioning sequence consisted of single problems with multiple internal steps.

Lehman, Jeffery R., John J. Koran, Jr., and Mary Lou Koran. "Interaction of Learner Characteristics with Learning from Three Models of the Periodic Table." Journal of Research in Science Teaching 21 (9): 885-893, December 1984.

One-hundred sixty high school chemistry students were the subjects of a study with four purposes: (1) to determine how students' achievement was affected by the use of periodic tables modified with visual and numerical data, (2) to determine how students' achievement was affected by the location of the Periodic Table within instructional materials, (3) to determine how students' achievement was affected by the use of a two page outline showing relationships between topics of the textbooks and the Periodic Table, and (4) to determine the difference in achievement of concrete- and formal-operational students. Tests taken from the Kit of Reference Tests for Cognitive Factors were used to assess cognitive abilities. Upon analysis of the data, the authors concluded that students using the modified tables containing color and atomic diagrams achieved at significantly higher levels than students using the traditional table or the table modified with additional numerical data. The authors further determined that the location of the Periodic Table within the instructional materials and the use of an outline did not influence student achievement. Finally, the authors ascertained that concrete-operational students benefitted from the location of the Periodic Table when it was placed directly alongside the instructional materials. The location of the Periodic Table did not influence the achievement of formal-operational students.

Okebukola, Peter Akinsola. "Students' Performance in Practical Chemistry: A Study of Some Related Factors." Journal of Research in Science Teaching 24 (2): 119-126, February 1987.

Eight-hundred nineteen grade 11 chemistry students from Nigeria were the subjects of a study designed to determine the factors that affect students' performance in laboratory chemistry. Data was collected by The Teachers' Laboratory Information and Attitude to Chemistry Questionnaire (TLIAQ), the Students' Laboratory Information and Attitude to Chemistry Questionnaire (SLIAQ), and the Class Participation Scale (CPS). Laboratory performance was assessed through a laboratory practical requiring the students to make observations, collect and record data, handle laboratory equipment, and perform mathematical calculations. The Practical Skills Assessment Criteria, an author designed analysis measure, was used to summarize the students' responses. Analysis of all the data, indicated that sutdents' performance in laboratory chemistry was significantly influenced by the participation in adequate and useful laboratory exercises. Other factors contributing to students' performance were the students' attitudes towards chemistry, the instructor's attitudes towards lab work, and the availability of laboratory equipment.

Shamai, Ruth and Ruth Stavy. "Teaching an Introductory Course in Qualitative Analysis in Order to Enhance Learning in General Chemistry." Journal of Chemical Education 63 (8): 707-708, August, 1986.

Seventy-three high school chemistry students were the subjects of a study designed to determine the effects that an introductory course in qualitative analysis had on the understanding and achievement of the chemical topic of electrolytes. The students were classified as concrete-operational and formal-operational thinkers through the use of a Lawson cognitive test. Achievement was measured through five tests each containing four types of test problems: (1) theoretical, (2) formulational, (3) computational, and (4) general equilibrium. After treatment and upon analysis of the data, Shamai and Stavy concluded that the overall achievement of the experimental group was significantly higher than that of the control group. Further analysis indicated that the experimental group exhibited higher acheivement for all problem types, with highest levels of achievement shown in theoretical and formulational problems. Differential effects were noted for concrete-operational and formal-operational thinkers, with formal-operational thinkers attaining more from the introductory course than concrete-operational thinkers.

Staver, John R. and Douglas A. Halsted. "The Effects of Reasoning, Use of Models, Sex Type, and Their Interactions on Posttest Achievement in Chemical Bonding after Constant Instruction." Journal of Research in Science Teaching 22 (5): 437-447, July 1985.

Eighty-four high school chemistry students were the subjects of a study designed to determine the effects that four factors had on the achievement of the chemical concept of bonding. The four factors were: (1) reasoning, (2) use of concrete models, (3) sex type, and (4) interactions of the previous three. The chemical topics taught were bonding, molecular geometry, Lewis structures, and molecular polarity. The posttest consisted of memory, application, and synthesis questions. Cognitive reasoning abilities were assessed by means of the Piagetian Logical Operations Test (PLOT). Students were randomly assigned to experimental and control groups. Upon analysis of the data, the authors concluded that achievement was significantly related to reasoning ability. Individually, the use of concrete models or sex type did not relate to achievement on the posttest. Interactions of reasoning ability, use of concrete models, and sex type indicated that concrete-operational females achieved at higher levels than formal-operational females when concrete models were not used during testing. Formal-operational females achieved at higher levels than concrete-operational females when concrete models were used during testing. Formal-operational males achieved at higher levels than concrete-operational males whether or not concrete models were used during testing.

SUMMARY

A review of the literature concerning the factors affecting high school students' achievement in chemistry courses revealed that research focussed on three main categories: (1) cognitive abilities affecting achievement, (2) instructional methods affecting achievement, and (3) teaching strategies affecting achievement.

One of several studies of cognitive abilities and chemistry achievement was the Wheeler and Kass (1977) study of proportional reasoning ability in chemistry. From the data gathered, the authors came to four conclusions: (1) Achievement in chemistry was significantly correlated with proportional reasoning ability; (2) Students with proportional reasoning ability achieved at significantly higher levels than students without proportional reasoning ability; (3) Proportional reasoning ability was related to cognitive level; (4) Chemistry instruction in proportional reasoning did not enhance general proportional reasoning ability. Krajcik and Haney's study of proportional reasoning ability in relation to high school chemistry achievement, revealed that proportional reasoning ability was necessary for achievement. The authors also stated that formal-operational students achieved at significantly higher levels than concrete-operational students. In addition, Krajcik and Haney noted that proportional reasoning ability was required for determination of solutions to problems that were identified as test discriminators. In a study assessing the problem solving skills utilized by students who were successful in solving volumetric analysis problems, Anamuah-Mensah, Erickson, and Gaskell concluded that proportional

reasoning ability did not affect the performance of students using algorithms without understanding, but did affect the success of students using algorithms with understanding. In an earlier study of cognitive strategies utilized by high school chemistry students to solve volumetric analysis problems, Anamuah-Mensah (1986) came to seven conclusions: (1) The two methods used by students to solve volumetric analysis problems were the Formula Approach and the Proportional Approach; (2) The majority of the students used the Formula Approach; (3) Students using the Formula Approach did not understand the relationships among the variables in the problems; (4) Students using the Proportional Approach did understand the relationships among the variables in the problems; (5) Difficulties in problem solving arose when students did not comprehend the proportional relationship between volume and concentration; (6) Achievement was not affected by the type of strategy used; (7) High achievers were more successful at solving problems than were low achievers.

Another portion of the research on cognitive ability and chemistry achievement dealt with specific cognitive factors affecting achievement. McNaught's study of cognitive preferences and chemistry achievement revealed that the cognitive preferences of memory, application, questioning, and principles were significantly correlated with achievement and were related to achievement in specific items on an achievement exam. In their study of the role and influence that four cognitive factors had on chemistry achievement, Chandran, Treagust, and Tobin determined that the factors of formal reasoning and prior knowledge were significantly related to achievement in chemistry while the cognitive factors of memory capacity and field dependence/independence were not significantly related to achieve-

ment. The authors recommended further research on the latter two cognitive factors. Research conducted by Staver and Jacks (1988) to determine the factors that influenced students' abilities to balance chemical equations identified the cognitive factor of prior knowledge as being significantly correlated to students' abilities in balancing chemical equations. When the cognitive factors of prior knowledge, restructuring ability, and working memory capacity were considered collectively, only restructuring ability was found to increase student performance in balancing equations. The authors also determined that working memory capacity, prior knowledge, and restructuring ability were highly correlated with students' achievement on specific posttest items. Working memory capacity was found not to influence overall achievement in balancing equations.

Cantu and Herron's study of abstract and concrete science concept attainment indicated that students classified as formal-operational thinkers achieved at significantly higher levels than students classified as concrete-operational thinkers. The study of student misconceptions of the chemical topic of equilibrium conducted by Wheeler and Kass (1978) identified misunderstandings of the equilibrium constant, Le Chatelier's Principle, and competing equilibria as misconceptions associated with chemistry achievement. The misconception of competing equilibria, along with the misconceptions of concentration and mass, and reaction rate and extent, were found to be associated with students' cognitive abilities.

The second category of research dealt with instructional methods that affected students' achievement in chemistry. In an early study, Hardy compared a CHEM Study chemistry course to a traditional chemistry

course to assess their effects on achievement and critical thinking ability. Analysis of the data led the author to conclude that the CHEM Study course resulted in higher student achievement than did the traditional course. Hardy also noted that the interactions of the instructional methods used and the cognitive abilities of the students did not result in any significant relationships with students' chemistry achievement or their levels of critical thinking ability. Hardy further noted that a student's I.Q. was the most significant factor in determining chemistry achievement.

A study of mastery learning feedback systems conducted by Swanson revealed that Keller's Personalized System of Instruction (PSI) and Bloom's Learning for Mastery (LFM) both resulted in significantly higher chemistry achievement than traditional methods. Bloom's LFM system was determined to result in higher chemistry achievement than Keller's PSI system. A greater number of course objectives were attained by students in both mastery systems than were attained by students in the traditional chemistry course. Dillashaw and Oakey studied the effects of a modified mastery learning strategy on students' chemistry achievement, attitudes towards science, and on-task behavior. Experimental groups in their research consisted of student directed remediation and teacher directed remediation groups. Analysis of the data led Dillashaw and Oakey to conclude that both modified mastery learning groups demonstrated higher achievement and on-task behavior than did the traditional group. Positive attitudes towards science were correlated with the student managed remediation group.

Other research on instructional methods and chemistry achievement also indicated that students' achievement had been affected by specific methods. In a 1987 study conducted by Mulopo and Fowler to determine

the differential effects of traditional and discovery approaches upon learning outcomes of chemical topics, the understanding of science and scientists, and attitudes towards science, the authors concluded that the traditional method of instruction resulted in significantly higher achievement of chemical concepts. The author further determined that the discovery approach was more effective in promoting understanding about science and scientists, and in developing positive attitudes about science. An analysis of the interactions of cognitive ability and approach used did not indicate any correlation with students' achievement. The authors finally concluded that formal-opertional students achieved at significantly higher levels than concrete-operational students. Inductive and deductive programmed instructional methods were compared in a study by Sakmyser. Chemistry achievement was determined not to be significantly different in either course. Additional analysis led Sakmyser to conclude that students with high reading abilities who were in the deductive program, showed significantly higher achievement than students with low reading abilities in the same program. Students with strong algebra abilities in the inductive program achieved at significantly higher levels than students with weak algebra abilities in the same program. Achievement in either program was not affected by students' cognitive styles. The author further noted that personality traits, such as exvia and invia, anxiety, cortertia and pathemia, field independence, and creativity did affect the achievement of students in each of the programmed courses. Harty and Al-Faleh concluded that small group lab instruction methods resulted in significantly higher levels of student achievement than did a lecture demonstration instruction method. The small group lab method resulted in increased positive attitudes towards science. Kletzly, in her study of tradi-

tional and Piagetian-based instruction methods on chemistry achievement resulted in the conclusion that Piagetian-based instruction resulted in higher chemistry achievement for both concrete- and formal-operational students. Achievement of students classified as transitional-operational was significantly higher in the Piagetian-based instructional groups than in the traditional instruction groups.

The sequence of learning cycle activities in high school chemistry was the focus of a study by Abraham and Renner. Through the rearrangement of the three phases of a learning cycle instructional methods, the authors concluded that the position of the invention (I) phase was related to chemistry achievement. For review concepts, the ideal location of the invention phase was between the gathering data (G) and expansion (E) phases. If the concept being taught was a new concept, the location of the invention phase was dependent upon the cognitive abilities of the students. Concrete-operational students achieved at higher levels if the invention phase was placed last in the sequence. For formal-operational students, achievement was highest if the invention phase was placed first in the sequence. An increase in positive science attitudes was seen when the invention phase was placed last in the sequence.

In an isolated study of teaching styles in high school chemistry courses and junior high general science courses, Wolfson concluded that the number of teacher-student interactions had an affect on the achievement of the students. Students under the tutelage of teachers exhibiting a high I/D ratio had significantly higher achievement and retention of science concepts than did students of low I/D ratio teachers. Further research was recommended in the area of retention tests.

The final category of research concerned with factors affecting chemistry achievement centered on specific teaching strategies. A few studies focussed on the use of concrete materials as a means to enhance chemistry achievement. These studies had mixed results. Goodstein's study of the use of concrete models indicated that the achievement of formal-operational thinkers was increased by the use of the models, but that the achievement of concrete-operational students was not improved. The author suggested that before teachers used concrete models to enhance chemistry achievement, the cognitive abilities of the students, the conceptual difficulties of the science topic being taught, and the method of instruction needed to be considered. In the Gabel and Sherwood (January 1980) study, it was concluded that both concrete- and formal-operational students who utilized concrete models throughout the entire course of chemistry instruction achieved at significantly higher levels than did students who merely watched their instructors handle the models. Additional research studied the interaction of concrete material and other variables on chemistry achievement. Howe and Durr, in their study of the use of concrete materials combined with peer interaction, found that the learning of chemical concepts was enhanced for both concrete- and formal-operational thinkers when concrete models were used with peer facilitation. The authors further noted that the achievement levels of concrete-operational thinkers who used concrete models in a peer facilitation setting, were significantly higher than achievement levels of concrete-operational thinkers who did not. Levels of achievement for formal-operational thinkers in the experimental group were found to be higher than those of formal-operational thinkers in the control group. In a study of the use of concrete materials, reasoning levels, sex type, and

their interactions on chemistry achievement on a posttest, Staver and Halsted (1985) concluded that when considered individually, the use of concrete models or sex type was not related to achievement in chemistry. Interactions of reasoning ability, use of concrete models, and sex type showed that posttest achievement levels of concrete-operational females were higher than achievement levels of formal-operational females when models were not used during testing. Achievement levels of formal-operational males were found to be higher than concrete-operational males whether or not models were used during testing.

Other research sought to determine the effects that the use of analogies in teaching chemical concepts had on chemistry achievement. In Gabel and Sherwood's (October 1980) study of the effects of the use of verbal analogies on achievement in chemistry, on differential effects between formal- and concrete-operational thinkers, and on cognitive ability, the authors came to five conclusions: (1) The use of verbal analogies did not increase the chemistry achievement of all students; (2) Students determined to have lower formal reasoning abilities were helped more by the use of verbal analogies than were students with higher reasoning abilities; (3) Students who comprehended the analogies achieved at significantly higher levels than students who did not comprehend the analogies; (4) Additional practice problems assigned to the control group appeared to have benefitted students more than the analogies in the treatment group; (5) Cognitive levels were not changed by the use of verbal analogies. In a later study of analyzing difficulties associated with solving mole concept problems by using analogies, Gabel and Sherwood (1984) stated that although students understood the analogies used in the mole concept problems, there were difficulties within

the problems that hindered students success in solving them. From further analysis of the data, Gabel and Sherwood indentified the difficulties in the mole concept problems as: (1) the use of scientific notation, (2) multiple step problems, (3) the use of fractional quantities, (4) the use of the indirect article "a" and the term "one", and (5) the use of division instead of multiplication. Components of problems not affecting the students' abilities to solve the problems were particle size, large or small numbers not expressed in scientific notation, and the use of the word "bag" in place of the word "billion."

Another study by Gabel and Sherwood (1983) sought to determine whether specific problem solving strategies for four chemical topics were superior to others and whether certain strategies were beneficial to students with different verbal-visual preferences, proportional reasoning abilities, and math anxiety levels. Nine conclusions were reached by the authors: (1) Students with high proportional reasoning abilities and low math anxiety levels achieved at significantly higher levels than students with low proportional reasoning abilities and high math anxiety levels; (2) The factor-label method was best for mole concept problems; (3) The proportionality method was best for the gas law problems; (4) For students exhibiting high verbal and low visual preferences, the best methods of problem solving were the analogy and diagram methods; (5) For students exhibiting low verbal and visual preferences, the factor-label method and proportionality methods were best; (6) The factor-label method was best and the diagram method was worst for students with low visual and math anxiety levels; (7) The diagram method was best and the factor-label method was worst for students with low visual preferences and high math anxiety

levels; (8) The analogy method was best and the factor-label method was worst for students of high math anxiety levels and low proportional reasoning abilities; (9) The factor-label method was best and analogy method worst for students with low proportional reasoning abilities and math anxiety levels.

Other researchers studied chemistry achievement as it related to specific testing practices. Cassels and Johnstone altered the language on multiple choice chemistry tests and found that students' performance was affected. By changing terms of quantity from "least" to "most", negative terms ("is not") to positive terms ("is"), complex scientific terms to simple terms, and shortening complex clauses, students' achievement on multiple choice chemistry tests increased. Verb tense changes from passive to active did not affect students' achievement. DeBoer analyzed testing in another way. His research on the effect of retesting on end-of-semester performance and on procrastination showed that low ability students did increase achievement in course objectives. Procrastination was found not to have affected the achievement of students at any level. In a study of the questioning format on a mole concept test, Lazonby, Morris, and Waddington found that achievement was significantly higher if the problems were written in a sequence of individual steps rather than written as one problem with multiple internal steps.

Other research dealt with achievement in the laboratory component of high school chemistry courses. It was concluded by Kempa and Ward in a study of observational attainment in laboratory chemistry, that achievement was related to the format of the lab reports. Although the highest rate of achievement was reported for students using a check list

lab report format, it was noted that this format gave rise to high illusionary error rates. Lowest achievement and highest omission error rates resulted from the use of a partial-direction lab report format. The author recommended further research to assess means to lower the illusionary error rate associated with the check list lab report format. In Okebukola's research of factors affecting achievement in laboratory chemistry, the author found that participation in adequate and useful laboratory exercises significantly increased students' achievement in the laboratory component of a chemistry course. Other factors that affected students' achievement were their attitudes towards chemistry, the instructor's attitude toward laboratory work, and the availability of laboratory equipment.

Isolated studies of the effects that specific teaching strategies had on chemistry achievement indicated that the enhancement of course content and the alteration of instructional materials led to increased student achievement. In a study conducted by Shamai and Stavy, it was determined that an introductory course in qualitative analysis prior to the teaching of the chemical topic of electrolytes increased students' achievement. The authors further noted that achievement gains were made on theoretical, formulational, computational, and general equilibrium problems on achievement tests. The authors also noted that formal-operational thinkers gained more from the introductory course than did concrete-operational thinkers. Lehman, Koran, and Koran analyzed the effects that the alteration of the appearance of the Periodic Table had on students' achievement in chemistry. The authors determined that students using the Periodic Table modified with color and diagrams achieved at significantly higher levels than students using the traditional Periodic Table or a Periodic Table enhanced with additional nu-

merical data. The authors also sought to determine if the location of the Periodic Table within instructional materials affected students' achievement. The data indicated that the location of the Periodic Table within instructional materials did not strongly influence achievement. Additional analysis showed that concrete-operational students benefitted from the placement of the Periodic Table alongside instructional materials. The position of the Periodic Table did not influence the achievement of formal-operational students. Finally, the authors analyzed the effects that the use of a two page outline correlating textbook information with the Periodic Table had on chemistry achievement. The data indicated that the outline did not influence students' achievement.

CONCLUSION

Through numerous research studies about the relationship between cognitive abilities and achievement in high school chemistry courses, it was determined that proportional reasoning ability was necessary for achievement (Wheller and Kass, 1977; Krajcik and Haney; Anamuah-Mensah, Erickson, and Gaskell). Chandran, Treagust, and Tobin, and Staver and Jacks determined that specific cognitive factors such as prior knowledge and restructuring abilities affected students' achievement in chemistry courses. McNaught's study of cognitive preferences and chemistry achievement revealed that cognitive preferences of memory, application, questioning, and principles were all correlated with chemistry achievement. Cantu and Herron's study revealed that formal-operational thinkers achieved at significantly higher levels than concrete-operational thinkers.

Research that dealt with instructional methods and chemistry achievement determined that certain methods did enhance achievement while other methods did not. Hardy found the CHEM Study course to be superior to a traditional chemistry course in the context of student achievement. Research on mastery learning methods and chemistry achievemend indicated that such methods did enhance student achievement (Swanson; Dillashaw and Oakey). Mulopo and Fowler's research determined that a discovery approach to chemistry instruction improved student achievement. In a study of inductive and deductive programmed chemistry courses, Saksmyser found that achievement was dependent upon other variables such as reading and algebra abilities. Small group laboratory instruction was found to increase student achievement (Harty and Al-Faleh). Pia-

getian-based instruction groups exhibited higher achievement than traditional instruction groups (Kletzly). Learning cycle approaches in chemistry courses resulted in higher achievement when the invention phase was in the correct placement in the cycle (Abraham and Renner). Additionally, teacher-student interaction was found to be a factor affecting student achievement in high school chemistry courses (Wolfson).

In the research concerned with the effects that specific teaching strategies had on chemistry achievement, it was determined that the use of analogies had student specific effects on achievement (Gabel and Sherwood, October 1980; Gabel and Sherwood, 1983). The research concerned with the use of concrete material to enhance chemistry achievement was inconclusive. Goodstein stated that only formal-operational students increased their achievement while Gabel and Sherwood (January 1980) found that both concrete- and formal-operational students benefitted from the use of concrete models. Staver and Halsted concluded that the use of concrete models to enhance achievement was gender and reasoning level dependent. Howe and Durr found that manipulation of concrete models combined with peer facilitation resulted in increased achievement for both concrete- and formal-operational students Gabel and Sherwood's (1983) study of problem solving strategies determined that strategies were chemical topic dependent and student dependent. The authors found that verbal-visual preferences and math anxiety levels influenced the use of specific strategies. Other research revealed that test format and language had an affect on student achievement (Lazonby, Morris, and Waddington; Cassels and Johnstone). DeBoer found that retesting increased achievement for low ability students. In research concerned with laboratory chemistry, Kempa and Ward determined that lab report formats had an affect

on student achievement. Okebukola ascertained that adequate and useful laboratory exercises had a significant affect on student achievement. Finally, it was discovered that color and diagram enhancement of the Periodic Table resulted in higher student achievement (Lehman, Koran, and Koran).

RECOMMENDATIONS

After review of the literature concerning the factors that affect student achievement in high school chemistry courses, the following recommendations are made to high school chemistry teachers:

1. Identify students according to cognitive abilities, cognitive preferences, reading abilities, and algebra abilities.
2. Vary instructional methods; utilize mastery learning techniques, small group laboratory methods, or Piagetian-based instructional methods.
3. Increase the number of positive teacher-student interactions.
4. Use concrete materials to discuss and explain abstract concepts.
5. Teach a variety of problem solving methods.
6. Have students participate in adequate and useful laboratory exercises.
7. Enhance the Periodic Table with color and atomic diagrams.
8. Use peer-facilitation along with concrete materials.
9. Modify language and problem format on tests and quizzes.
10. Use scientific notation sparingly unless students have a strong understanding of the concept.
11. Use check list lab report format unless students have developed strong observational skills.
12. Use analogies cautiously.

BIBLIOGRAPHY

Abraham, Michael R. and John W. Renner. "The Sequence of Learning Cycle Activities in High School Chemistry." Journal of Research in Science Teaching 23 (2): 121-143, February 1986. (4,5,13,31,39)

Anamuah-Mensah, J. "Cognitive Strategies Used by Chemistry Students to Solve Volumetric Analysis Problems." Journal of Research in Science Teaching 23 (9): 759-769, December 1986. (5,6,8,27)

Anamuah-Mensah, Jophus, Gaalen Erickson and Jim Gaskell. "Development of a Path Analytical Model of Students' Performance in Chemistry." Journal of Research in Science Teaching 24 (8): 723-738, November 1987. (8,26,38)

Brown, Theodore L. and H. Eugene LeMay. Chemistry: The Central Science. 4th ed. Englewood Cliffs: Prentice-Hall, 1988. (4,5,6,7)

Cassels, J. R. T. and A. H. Johnstone. "The Effect of Language on Student Performance on Multiple Choice Tests in Chemistry." Journal of Chemical Education 61 (7): 613-615, July 1984. (2,18,35,39)

Cantu, Luis L. and J. Dudley Herron. "Concrete and Formal Piagetian Stages and Science Concept Attainment." Journal of Research in Science Teaching 15 (2): 135-143, January 1978. (1,4,6,9,28,38)

Chandran, Sarath, David F. Treagust, and Kenneth Tobin. "The Role of Cognitive Factors in Chemistry Achievement." Journal of Research in Science Teaching 24 (2): 145-160, February 1987. (1,9,27,38)

Chiappetta, Eugene L. "A Review of Piagetian Studies Relevant to Science Instruction at the Secondary and College Level." Science Education 60 (2): 253-261, February 1976. (1)

DeBoer, George E. "The Effect of Retesting on End-of-Semester Performance in High School Chemistry at Three Levels of Previous Science Achievement." Journal of Research in Science Teaching 18 (3): 261-267, May 1981. (18,35,39)

Dillashaw, F. Gerald and James R. Oakey. "Effects of a Modified Mastery Learning Strategy on Achievement, Attitudes, and On-Task Behavior of High School Chemistry Students." Journal of Research in Science Teaching 20 (3): 203-211, March 1983. (1,6,13,29,38)

Gabel, Dorothy and Robert Sherwood. "The Effect of Student Manipulation of Molecular Models on Chemistry Achievement According to Piagetian Level." Journal of Research in Science Teaching 17 (1) 75-81, January 1980. (1,19,32,39)

Gabel, Dorothy L. and Robert D. Sherwood. "Effect of Using Analogies on Chemistry Achievement According to Piagetian Level." Science Education 64 (5): 709-716, October 1980. (19,33,39)

Gabel, Dorothy L. and Robert D. Sherwood. "Facilitating Problem Solving in High School Chemistry." Journal of Research in Science Teaching 20 (2): 163-177, February 1983. 1,20,34,39)

Gabel, Dorothy and Robert D. Sherwood. "Analyzing Difficulties with Mole-Concept Tasks by Using Familiar Analog Tasks." Journal of Research in Science Teaching 21 (8): 843-851, November 1984. (1,21,33)

Good, Carter V., Editor. Dictionary of Education. 2nd ed. New York: McGraw-Hill, 1973. (4,5)

Goodstein, Madeline. "The Use of Concrete Methods in Secondary Chemistry Instruction." Journal of Research in Science Teaching 15 (5): 361-366, June 1978. (1,21,32,39)

Hardy, Clifford A. "CHEM Study and Traditional Chemistry: An Experimental Analysis." Science Education 54 (3): 273-276, March 1970. (14,28,38)

Harty, Harold and Nasser Al-Faleh. "Saudi Arabian Students' Chemistry Achievement and Science Attitudes Stemming from Lecture Demonstration and Small Group Teaching Methods." Journal of Research in Science Teaching 20 (9): 861-866, December 1983. (1,14,30,38)

Howe, Ann C. and Beulah Durr. "Using Concrete Materials and Peer Interaction to Enhance Learning in Chemistry." Journal of Research in Science Teaching 19 (3): 225-232, March 1982. (1,7,22,32,39)

Kempa, R. F. and J. E. Ward. "The Effect of Different Modes of Task Orientation on Observational Attainment in Practical Chemistry." Journal of Research in Science Teaching 12 (1): 69-76, January 1975. (5,6,22,35,39)

Kletzly, Nellie E. "The Effects of Two Methods of Teaching Abstract Topics in High School Chemistry." Educational Resources Information Center, ED 199 063, Sam Houston State University, August 1980, 86 pages. (6,7,15,30,39)

Krajcik, Joseph S. and Richard E. Haney. "Proportional reasoning and Achievement in High School Chemistry." School Science and Mathematics 87 (1): 25-32, January 1987. (7,10,26,38)

Lazonby, John N., Jane E. Morris, and David J. Waddington. "The Mole: Questioning Format Can Make a Difference." Journal of Chemical Education 62 (1): 60-61, January 1985. (2,23,35,39)

Lehman, Jeffery R., John J. Koran, Jr., and Mary Lou Koran. "Interaction of Learner Characteristics with Learning from Three Models of the Periodic Table." Journal of Research in Science Teaching 21 (9): 885-893, December 1984. (23,36,40)

McNaught, Carmel. "Relationship Between Cognitive Preferences and Achievement in Chemistry." Journal of Research in Science Teaching 19 (2): 177-186, February 1982. (1,4,6,7,10,27,38)

Mulopo, Moses M. and Seymour H. Fowler. "Effects of Traditional and Discovery Instructional Approaches on Learning Outcomes for Learners of Different Intellectual Development: A Study of Chemistry Students in Zambia." Journal of Research in Science Teaching 24 (3): 217-227, March 1987. (4,15,29,38)

Okebukola, Peter Akinsola. "Students' Performance in Practical Chemistry: A Study of Some Related Factors." Journal of Research in Science Teaching 24 (2): 119-126, February 1987. (24,36,39)

Sakmyser, Diane D. "Comparison of Inductive and Deductive Programmed Instruction on Chemical Equilibrium for High School Chemistry Students." Journal of Research in Science Teaching 11 (1): 67-77, January 1974. (4,5,6,16,30,38)

Shamai, Ruth and Ruth Stavy. "Teaching an Introductory Course in Qualitative Analysis in Order to Enhance Learning in General Chemistry." Journal of chemical Education 63 (8): 707-708, August, 1986. (24,36)

Staver, John R. and Douglas A. Halsted. "The Effects of Reasoning, Use of Models, Sex Type, and Their Interactions on Posttest Achievement in Chemical Bonding after Constant Instruction." Journal of Research in Science Teaching 22 (5): 437-447, July 1985. (24,33,39)

Staver, John R. and Tom Jacks. "The Influence of Cognitive Reasoning Level, Cognitive Restructuring Ability, Disembedding Ability, Working Memory Capacity, and Prior Knowledge on Students' Performance on Balancing Equations by Inspection." Journal of Research in Science Teaching 25 (9): 763-775, December 1988. (1,4,11,28)

Swanson, David H. "A Comparison of Mastery Learning Feedback Systems Affecting Achievement in Chemistry." Educational Resources Information Center, ED 139 650, American Educational Research Association, April 1977, 17 pages. (1,4,5,16,29,38)

Wheeler, Alan E. and Keidi Kass. "Proportional reasoning in Introductory High School Chemistry." Educational Resources Information Center, ED 139 620, National Association for Research in Science Teaching, March 1977, 31 pages. (11,26,38)

Wheeler, Alan E. and Heidi Kass. "Student Misconceptions in Chemical Equilibrium." Science Education 62 (2): 223-232, February 1978. (5,12,28)

Wolfson, Morton L. "A Consideration of Direct and Indirect Teaching Styles with Respect to Achievement and Retention of Learning in Science Classes." Journal of Research in Science Teaching 10 (4): 285-290, April 1973. (5,17,31,39)

Zumdahl, Steven S. Chemistry. Lexington: D. C. Heath, 1986. (6,7)